

An important contribution to the volatile history of Mars comes from a detailed study of Valles Marineris, where excellent stereoimages and a three-dimensional view of the upper Martian crust permit unusual insights: the subsurface in the equatorial region of Mars below about 1 km depth was not desiccated until relatively recently, even though desiccation is predicted by models of the equilibrium between water in the ground and in the atmosphere [1].

The evidence that ground water and ice existed until relatively recently or still exist in the equatorial area comes from observations of landslides [2,3], wall rock [4], and dark volcanic vents [5,6]. Several observations suggest that landslides were lubricated by water. Three young slides generated an outwash fan and gave rise to a channel that has several bends and extends on a gradient of 4 m/km for a total distance of 250 km from its source [7]. Also, the material in this channel was capable of erosion at considerable distance from its source; it breached a bedrock ridge, carved flutes in the lower channel, and eroded its banks. Doughnut-shaped hills within this channel resemble moraines containing kettle holes, which on Earth are formed by the melting of blocks of ice.

Some landslides have lobes that angle backward from the main debris mass and flow downhill, others give rise to small sinuous valleys, and many small landslides are surrounded by levees like terrestrial mudflows. These observations also suggest that the landslide deposits contained fluids. A small channel debouches from a tributary canyon to Valles Marineris; apparently water discharged from the canyon walls, if canyon tributaries were indeed formed by sapping [9].

Valles Marineris landslides are different in efficiency from large catastrophic landslides on Earth. Whereas terrestrial landslides increase in efficiency (distance traveled) with increasing weight [9], the large landslides in Valles Marineris retain the same efficiency regardless of weight [3]. One explanation for the difference might be that the Martian slides are lubricated by water, whereas most large terrestrial slides are dry-rock avalanches [10].

A comparison of landslide speeds also suggests that the Martian slides contained water. Among large catastrophic landslides on Earth, only the Huascaran slide [11] matches the Martian ones in speed [3]; the Huascaran slide contained much water and ice. Because all landslides in Valles Marineris are released from wall rock, some layers within the walls that are 7-10 km high must have contained these lubricating materials.

A relatively young, level deposit embaying eroded layered beds occurs in the lowest area of the central troughs of Valles Marineris [12]. The deposit looks like a dry lake bed or alluvial flat, which suggests that wet debris contributed to its formation. The wet debris was apparently derived from landslides or wall rock.

That Valles Marineris wall rock contained water or ice is further suggested by its difference from the interior layered deposits. Landslides having flow lobes that extend far out onto the chasma floors debouch only from wall rock or erosional remnants of wall rock. No such landslides come from the layered deposits, even where the layered deposits are as high and steep as the wall rock. Apparently, landslides formed from the wall materials flowed easily; those from the interior deposits generally did not [13].

Faults and fault zones in Valles Marineris also shed light on the problem of water content in the walls. Contrary to what is commonly seen on Earth, many fault zones in Valles Marineris are more resistant to erosion than the country rock. Spurs projecting into Valles Marineris developed along faults [4], and all the median ridges of wall rock paralleling chasma walls or separating chasmata from each other occur where faults and fracture zones are densely spaced. Apparently faults were lithified or intruded by dikes and thus are more resistant to erosion than the country rock. Conversely, the observation implies that the country rock is weaker relative to the faults. Such weak country rock would be consistent with wall rock composed of breccia [10] that is weakly cemented by ice near the free faces and is charged with water at some depth.

Another argument supports the idea that the wall rock contained water and ice. Dark deposits interpreted as volcanic-vent material [5,6] occur only at elevations lower than 6 km above Martian datum. The highest deposits are 3 km below the rim of adjacent plateau surfaces. This 6-km elevation appears to be the maximum height reached by extruding magmas and can be used to calculate relative densities of magma and wall-rock columns [14,15]. It appears that the material in the column of combined solid crust and mantle rock underlying the plateau must have been less dense than the material in the liquid magma column. Upper crustal rock composed of loosely consolidated breccia mixed with water or ice might fulfill such a requirement.

Because the main evidence for water and ice in the wall rock comes from landslides, their time of emplacement is important. The landslides in Valles Marineris date from the time of late eruptions on the Tharsis volcanoes [2] and thus were emplaced after the major activity on Martian outflow channels. Therefore, the concept of ground saturated by water and ice in the equatorial region is consistent with Carr's [16] hypothesis that confined aquifers developed in this region and gave rise to outflow channels. The concept also agrees with the presence of rampart craters in the equatorial area.

None of the above observations conclusively demonstrate that water or ice existed in the wall rock of Valles Marineris, but altogether the evidence is highly suggestive. Any models addressing the exchange of water with the atmosphere in the equatorial region of Mars must therefore take into account that, below a depth of about 1 km, this region was not entirely desiccated, at least until the time of landslide formation.

#### References

- 1) Fanale F. R. (1976) Icarus, 28, p. 179-202.
- 2) Lucchitta B. K. (1979) J. Geophys. Res., 84, p. 8097-8113.
- 3) Lucchitta B. K., Kaufman K. L., and Tosline D. J. (1981) NASA TM 84211, p. 326-328.
- 4) Lucchitta B. K. (1981) NASA TM 84211, p. 419-421.
- 5) Lucchitta B. K. (1985) Lunar Planet. Sci. XVI, p. 503-504.
- 6) Lucchitta B. K. (1986) Lunar Planet. Sci. XVII, p. 496-497.
- 7) Lucchitta B. K. (1984) Workshop on Water on Mars, Nov. 30-Dec. 1, 1984, p. 45-47.
- 8) Pieri David (1980) Science, 210, p. 895-897.
- 9) Scheidegger A. E. (1973) Rock Mechanics, 5, p. 231-236.
- 10) Hsü K. J. (1975) Geol. Soc. Am. Bull., 86, p. 129-140.

- 11) Plafker George and Erickson G. E. (1978) Rock slides and avalanches, Barry Voight, ed., Elsevier, Amsterdam, p. 277-314.
- 12) Lucchitta B. K. and Ferguson H. M. (1983) Proc. Lunar Planet. Sci. Conf. 13th, Part 2, 88, Supplement, p. A553-A568.
- 13) Lucchitta B. K. (1982) Repts. Planet. Geol. Prog.-1982: NASA TM 85127, p. 233-234.
- 14) Eaton J. P. and Murata K. J. (1960) Science, 132, p. 925-938.
- 15) Vogt P. R. (1974) Earth and Planet. Sci. Letts., 23, p. 337-348.
- 16) Carr M. H. (1979) J. Geophys. Res., 84, p. 2995-3007.

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